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(54) POLARIZATION-INDEPENDENT OPTICAL ISOLATOR

(57) The present invention relates to an optical isolator for interrupting reflection-returned light from going back in an optical system in the case of optical fiber communication, inputting and outputting of optical discs, etc. using semiconductor laser. It is an object of the present invention in connection with the polarization-independent optical isolator to make unnecessary a complicated and difficult step for optically connecting the lenses and the optical fibers so as to collimate the light emitted from the light-incident side optical fiber, enhance the efficiency in coupling the light with the light-emitting side optical fiber again and prevent the return light from being coupled with the light-incident side optical fiber again. A polarization-indepedent optical isolator according to the present invention comprises a light-incident side optical fiber having a diameter of a core expanded to give a mode field diameter at an end face being 20 to 50 μm, a light-emitting side optical fiber having a diameter of a core expanded to give a mode field diameter at an end face being 20 to 50 μm, and an optical isolator element provided between the light-incident side optical fiber and the light-emitting side optical fiber, said optical isolator element comprising a first polarization beam splitter located at a side of the light-incident side optical fiber, a second polarization beam splitter located at a side of the light-emitting side optical fiber, and a Farady rotator provided between the first polarization beam splitter and the second polarization beam splitter, and at least said first polarization beam splitter being a wedge type polarization beam splitter.

FIG. 1a

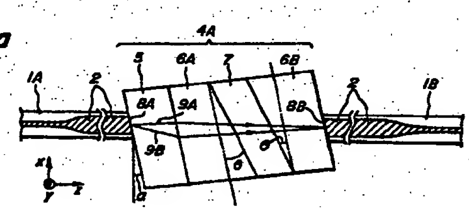
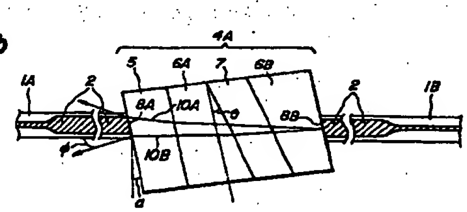


FIG. 1b



EP 0 786 681 A1

Description

[001]

(Field of the Invention)

The present invention relates to an optical isolator for interrupting reflection-returned light from going back in an optical system in the case of optical fiber communication, inputting and outputting of optical discs, etc. using semiconductor laser.

[002]

(Background art)

Polarization-independent optical isolators employing the semiconductor layer are often used for interrupting reflection-returned light in optical systems such as optical fiber communication systems and optical disc input/output devices. In particular, it is required that the polarization-independent optical isolator is attached to a optical fiber amplifier so as to prevent fluctuations in its outputs. The polarization-independent optical isolator using a polarization beam splitter functions in such a way that optical paths for respective polarized components having their polarized directions orthogonal to each other are separated or coupled (JP-B 60-49297, JP-B 61-58808, etc.).

[003]

Fig. 5 is a schematic view for showing a polarization-independent optical isolator using wedge type polarization beam splitters as proposed in JP-B 61-58809. A first lens 27A is opposed to an end face of a light-incident side optical fiber 26A, whereas a second lens 27B opposed to an end face of a light-emitting side optical fiber 26B. Arranged between the first lens 27A and the second lens 27B are a first wedge type polarization beam splitter 28, a Farady rotator 29 and a second wedge type polarization beam splitter 30 in this order.

[004]

Two polarized components being orthogonal to each other are emitted from the light-incident side optical fiber 26A, and pass the first lens 27A. As the polarized components pass the first wedge type polarization beam splitter 28, they undergo different refraction depending upon their polarizations, so that they are separated into two beams 31A and 31B. The polarization planes of the separated polarized components 31A and 31B are turned by the Farady rotator 29, and the polarized components are converted into parallel beams through their angular changes by means of the second wedge type polarization beam splitter 30. At this time, the polarized components emitted from the second wedge type polarization beam splitter 30 have the same orientation, but they are positionally deviated. This parallel light is focused into the light-emitting side optical fiber 26B by the second lens 27B.

[005]

On the other hand, a return light propagating in a backward direction is shown by dotted lines. Polarized components constituting the return light and being orthogonal to each other are binarily divided by the second wedge type polarization beam splitter 30, and the polarization plane of each of the polarized components separated is turned by the Farady rotator 29 in the same direction as the forward direction. As a result, the polarization direction in which the polarized component passes the first wedge type polarization beam splitter 28 differs from that in the case of the forward propagation by 90°. Consequently, the polarization components are deviated positionally and angularly from each other, different form the light beams in the forward propagation. After the polarized components pass the first lens 27A, they become the parallel beams, but their optical axes are positionally deviated from that of the optical fiber 26A, so that the parallel beams are not coupled with the light-incident side optical fiber.

[006]

Fig. 6 is a schematic view for showing a polarization-independent optical isolator using parallel-faced flat plate type polarization beam splitter as proposed in JP-B 60-49297. A first lens 27A is opposed to an end face of a light-incident side optical fiber 26A, whereas a second lens 27B opposed to an end face of a light-emitting side optical fiber 26B. Arranged between the lens 27A and the lens 27B are a first parallel-faced flat plate type polarization beam splitter 32, a Farady rotator 33, and second and third parallel-faced flat plate type polarization beam splitters 29, 34 in this order.

[007]

Two polarized components being orthogonal to each other are emitted from the light-incident side optical fiber 26A in a forward direction, and pass the first lens 27A. As the polarized components pass the first parallel-faced flat plate type polarization beam splitter 32, they are separated into two beams. The polarization plane of each polarized component is turned by the Farady rotator 33. Then, two orthogonal polarized components are positionally shifted by the second and third parallel-face flat plane type polarization beam splitters 29, 34 so that the components may be coupled with each other again. Then, the components are focused by the second lens 27B, and led to the light-emitting side optical fiber 26B. On the other hand, the polarized orthogonal components returning in a backward direction are binarily divided by the parallel-faced flat plate

type polarization beam splitters 34, 29 in the same manner as mentioned above, and each of the components has the same polarization plane as in case of the forward propagation, and the polarized components are led into the Farady rotator 33. The polarization plane of each polarized component is turned in the same direction as in the case of the forward propagation. As a result, the polarization direction in which the polarized component passes the first parallel-faced flat plate type polarization beam splitter 32 differs from that in the case of the forward propagation by 90°. Consequently, the polarization components are angularly the same but deviated positionally with respect to the light in the forward propagation. After the polarized components pass the first lens 27A, they become beams having a large angle, so that they are not coupled with the light-incident side optical fiber.

[008]

(Disclosure of the Invention)

However, the conventional polarization-independent optical isolators mentioned above have the following problems.

(1) In order to couple the polarization-independent optical isolator element as shown in Fig. 5 or 6 with the light-incident side optical fiber, it is necessary to collimate the light beams emitted from the light-incident side optical fiber. In order to enhance a backward-direction loss, it is indispensable that the position and the angle of the light are changed by the lens to prevent the axially deviated light propagating in the backward direction with the light-incident side optical fiber again. Further, with respect to the light-emitting side, it is necessary that the parallel light beams are effectively coupled again by the lens to reduce the loss. For these reasons, a pair of the lenses need provided between the light-incident optical fiber and the optical isolator and between the light-emitting side optical fiber and the optical isolator.

[009]

However, in order to align the optical system including such lenses, three-dimensional alignment including alignment of their focal points need be carried out one by one. In addition, such alignments require an extremely high precision and a long working time period as well as skill. In order to even slightly mitigate the above problems, an example of a focusing system with only one lens is proposed, but it is still necessary and indispensable to effect alignments at high precision in that the lens is coupled with the optical fiber.

[010]

In Fig. 5, since the first wedge type polarization beam splitter 28 to be used for separating the two polarized components once in the case of the forward propagation has birefringence property, an emitting direction of an ordinary rays differs from that of extraordinary rays. The emitting direction of the ordinary rays and that of the extraordinary rays are made equal by the second wedge type polarization beam splitter 30. However, since the location to which the ordinary rays are emitted to to the second wedge type polarization beam splitter 30 differs from that to which the extraordinary rays are emitted to this splitter, it is difficult to completely couple these polarized components, although the directions of the polarized components emitted are the same.

[011]

From the above reasons (1) and (2), unless the optical system is aligned at high precision and the light beams are coupled again, the input loss of the optical isolator is large and the polarization dependency occurs. In particular, unless the optical axes of the polarized components are aligned with each other at higher precision as the spot diameter of the light becomes smaller, the input loss becomes greater. However, generally speaking, it is extremely difficult to effect the optical axis alignment in which the two polarized components separated are coupled again, and aligned with a core of the optical fiber, and the losses of the two polarized components become different from each other. Therefore, it was not easy to reduce the polarization dependency with respect to the conventional polarization-independent optical isolators.

[012]

Under the circumstances, a method for lessen the positional deviation between the two polarized components as large as possible is disclosed in JP-A 5-224153. However, a special optical system (e.g. using a special and expensive prism) including an optical system composed of a light-incident side optical fiber and lens as well as a lens in a light-emitting optical system having an optical axis at a different location needs be added. Further, in order to obtain a high backward-direction loss, it was still necessary to rely upon changing of the location and the angle of the polarized components with the lenses.

[013]

(3) In the case of the polarization-independent optical isolator using the parallel-faced flat plate type polarization beam splitter 32 as shown in Fig. 6, in order to realize a high backward-direction loss, the return light must not be coupled with the light-incident side optical fiber 26A by sufficiently spacing

the location of the beams emitted in the backward direction from the light-incident location in the case of the forward propagating. For this purpose, it is necessary to increase the separation width of the parallel-faced flat plate type polarization beam splitter 32. As specific methods therefor, it is proposed that a sufficient length of the parallel-faced flat plate type polarization beam splitter 32 as viewed in the fiber-axis direction is ensured (JP-B 60-49297) and that the separation width is set at not less than 0.66 times as large as that of a fiber-propagated light MFD by using a lens (JP-A 7-43640).

[014]

(4) From the standpoint of convenience in assembling, light is preferably vertically introduced into the isolator element. However, the light is not only likely to be reflected at an interface, but also the optical axis of the light-incident side optical fiber is not the same as that of the light-emitting side optical fiber. Therefore, when a fiber-embedded type isolator is to be produced, the optical axis of each optical fiber is preliminarily deviated by a deviated amount between the above optical axes.

[015]

For the above reasons, if a polarization-independent optical isolator is to be produced provided that the isolator satisfies characteristics (generally, the input loss ≦ 1 dB, the backward-direction loss ≧ 40 dB) required by users, there was problems that the number of parts increased, the number of assembling steps largely increased, and the isolator became bulky and costy.

[016]

It is an object of the present invention in connection with the polarization-independent optical isolator to make unnecessary a complicated and difficult step for optically connecting the lenses and the optical fibers so as to collimate the light emitted from the light-incident side optical fiber, enhance the efficiency in coupling the light with the light-emitting side optical fiber again and prevent the return light from being coupled with the light-incident side optical fiber again.

[017]

Further, it is another object of the present invention to decrease the loss in the re-coupling between the ordinary rays and the extraordinary rays separated by the polarization beam splitter in the case of the forward propagation and to make unnecessary an optically coupling step required for effect the above re-coupling in the forward propagation. Further, it is a further object of the present invention to make the optical isolator compact. It is a still further object of the present invention to prevent deviation in the optical axis between the light-incident side optical fiber and the light-emitting side optical fiber.

[018]

Further, it is an additional object of the present invention to provide a polarization-independent optical isolator suitable for mass production by decreasing the number of parts and the number of assembling steps and making the separator compact, provided that the input loss is not more than 1 dB and the backward-direction loss is not less than 40 dB.

[019]

The polarization-indepedent optical isolator according to the present invention comprises a light-incident side optical fiber having a diameter of a core expanded to give a mode field diameter at an end face being 20 to 50 μm, a light-emitting side optical fiber having a diameter of a core expanded to give a mode field diameter at an end face being 20 to 50 μm, and an optical isolator element provided between the light-incident side optical fiber and the light-emitting side optical fiber, said optical isolator element comprising a first polarization beam splitter located at a side of the light-incident side optical fiber, a second polarization beam splitter located at a side of the light-emitting side optical fiber, and a Farady rotator provided between the first polarization beam splitter and the second polarization beam splitter, and at least said first polarization beam splitter being a wedge type polarization beam splitter.

[020]

The present inventors have succeeded in the production of the novel polarization-independent optical isolator which utilizes to the maximum the features as characteristics of the core-expanded optical fiber that tolerance in assembling in terms of the position and the direction is mitigated by a reduced numerical aperture and that the input loss is reduced by mitigating the diffracting effect. That is, the core-expanded optical fiber is characterized in that it has a smaller numerical aperture and high latitude in terms of the position and the direction, whereas the core-expanded optical fiber has an extremely narrow allowable range with respect to the angular deviation and less suffers input loss due to the diffracting effect in the case of the lens.

[021]

The present inventors have succeeded in providing the small size polarization-independent optical isolator, which can be more easily assembled as compared with the conventional optical isolators and at the same time has a high backward-direction loss and a low input loss,

by using the core-expanded optical fibers having the above characteristics as the light-incident side and light-emitting side optical fibers and using the wedge type polarization beam splitter in the optical isolator element without using even one lens between the light-incident and light-emitting optical fibers.

[022]

As mentioned above, according to the present invention, since the no lens is used contrary to the conventional optical isolators, the number of the parts can be decreased, and the cost can be reduced by eliminating the aligning step.

[023]

In the above, as the core-expanded optical fiber, an optical fiber described in K. Shiraishi, Y. Aizawa, and S. Kawakami, "Beam expanding fiber using thermal diffusion of the dopant"; IEEE J. Lightwave Technology, 8, 1151(1990)" may be preferably used. Further, as the polarization beam splitter, a birefringent crystal such as rutile and calcite and an artificial birefringent material made of a dielectric multi-layer film may be preferably used. As the Farady rotator, a material having a large Verdet constant, such as magnetic garnet, may be preferably used.

[024]

(Brief Description of the drawings)

Fig. 1(a) is a schematic view for illustrating a polarization-independent optical isolator as an embodiment of the present invention (a forward propagation being shown), Fig. 1(b) being a schematic view for showing a state in which light is propagated in the isolator of Fig. 1(a) in a backward direction;

Fig. 2 is a schematic view for showing a polarization-independent optical isolator as another embodiment according to the present invention;

Fig. 3 is a schematic view for showing a polarization-independent optical isolator as a further embodiment according to the present invention;

Fig. 4 is a schematic view for showing a polarization-independent optical isolator as a still further embodiment according to the present invention;

Fig. 5 is a schematic view for showing the polarization-independent optical isolator as a conventional example; and

Fig. 6 is a schematic view for showing the optical isolator as another conventional example.

[025]

(Best mode for carrying out the invention)

In a preferred embodiment, in order to correct the deviation in the optical axis between the ordinary rays and the extraordinary rays caused by the first polarization beam splitter, the second polarization beam splitter and the Farady rotator during the forward propagation, an optical axis deviation-correcting element made of a parallel-faced flat plate type polarization beam splitter is preferably provided. By doing so, the light-coupling efficiency in the forward direction is further enhanced.

[026]

In another preferred embodiment, not only the first polarization beam splitter but also the second polarization beam splitter are wedge type polarization beam splitters, and the first polarization beam splitter and the second polarization beam splitter are opposed to each other and turned by a half turn around axes of the optical fibers as a center. That is, the first and second polarization beam splitters are arranged symmetrically as a point with respect to the Farady rotator. Since the deviation in the optical axis between the light-incident side optical fiber and the light-emitting side optical fiber is removed in this way by using a pair of the wedge type polarization beam splitters, the optical axes are more easily aligned.

[027]

Further, the present invention will be explained in more detail with reference to the drawings.

Fig. 1(a) is a schematic view (in the forward propagation) for showing the polarization-independent optical isolator according to an embodiment of the present invention, and Fig. 1(b) a schematic view for showing an advancing way of the light when the light is propagated in the isolator of Fig. 1(a) in the backward direction. An input side end face of the light-incident side optical fiber and an output side end face of the light-emitting side optical fiber are omitted from the figures. In Fig. 1(a), the light emitted from an end face 8A of an expanded portion 2 of a core of a light-incident side optical fiber 1A and having a small numerical aperture is led into a parallel-faced flat plate type polarization beam splitter 5 at an incident angle α, and divided into two polarized components 9A and 9B. The two polarized components 9A and 9B enter a first wedge type polarization beam splitter 6A. Since this polarization beam splitter is made of a birefringent crystal, each polarized component is refracted inside this birefringent crystal, depending upon its refractive index. The polarization planes of the two polarized components having undergone different angular changes are turned by a Farady rotator 7, respectively.

[028]

While ordinary rays and extraordinary rays are not exchanged, the polarized components enter a second wedge type polarization beam splitter 6B where the polarized components are coupled again with each other. Since the optical axis of the re-coupled light is the same as that of an light-emitting side optical fiber 1B, the light enters an end face 8B of the fiber 1B. The thickness, etc. of the parallel-faced flat plate type polarization beam splitter 5 are preliminarily aligned to offset the positional deviation between the two polarized components, which would occur depending upon the incident angle α and a pair of the wedge type polarization beam splitters 6A and 6B.

[029]

What contributes to a polarized component-dividing function of the wedge type polarization beam splitter 6A is a wedge angle θ, which does not depend upon the thickness of the splitter. Therefore, different from the parallel-faced flat plate type polarization beam splitter, the polarized components can be assuredly divided from each other even by shortening the wedge type polarization beam splitter. Thus, the length of the isolator element may be small. Although not limited, a wedge type polarization beam splitter having a wedge angle θ of 10° to 40° is use, and particularly a wedge type polarization beam splitter having a wedge angle θ of around 20° is preferably used. By so doing, the low diffracting characteristic of the core-expanded optical fiber can be further utilized so that the input loss of the entire polarization-independent optical isolator element 4A can be reduced. Furthermore, the optical isolator can be conspicuously made compact.

[030]

Then, the light propagating in the backward direction will be explained. As shown in Fig. 1(b), the light emitted from the end face 8B of the light-emitting side optical fiber 1B and having a small numerical aperture is refracted, by the second wedge type polarization beam splitter 6B, depending upon the refractive index. The polarization planes of two polarized components shifted in respectively different directions are turned in the same direction as in the case of the incident polarized components by the Faraday rotator 7. Therefore, while the ordinary rays and the extraordinary rays are exchanged, each polarized component enters the first wedge type polarization beam splitter 6A. In the splitter 6A, each of polarized components undergoes the refraction depending upon its refractive index, so that the polarized components are not coupled into a single beam. In addition, the polarized components are positionally shifted by the parallel-faced flat plane polarization beam splitter 5.

[031]

Even if the positional deviation is slight, the propagating direction of the backward-direction light differs from the direction of the optical axis of the optical fiber because of the small numerical aperture of the core-expanded optical fiber. Therefore, it is difficult to couple the light with the optical fiber again, so that the backward-direction light components 10A or 10B does not enter the light-incident side optical fiber 1A. Therefore, a high backward-direction loss can be easily realized.

[032]

With respect to the light-incident side optical fiber and the light-emitting side optical fiber, an incident angle α at the end face of the optical fiber is preferably greater than 0° to make the reflection loss smaller. Even if the light enters vertically (incident angle 0°), no great influence is given upon the input loss and the backward-direction loss. Further, the diffraction loss amounts to about a half of the input loss, and the diffraction loss increases with increase in a gap at each of the end faces of a pair of the optical fibers. However, excess increase in the length of the gap between the end faces of the fibers can be prevented by setting the incident angle α at not more than 5°. If the incident angle exceeds the above upper limit, it may be difficult to align the input loss of the polarization-independent optical isolator to not more than 1 dB.

[033]

When a mode field diameter (MFD) of the core-expanded optical fibers constituting the light-incident side and light-emitting side optical fibers is set at not less than 20 μm, the input loss caused by the diffraction with no lens can be reduced, and the backward-direction loss can be increased by appropriately setting the numerical aperture. Further, increase in the excess loss can be prevented by setting the mode field diameter at not more than 50 μm. If the MFD is less than 20 μm or more than 50 μm, it is extremely difficult to ensure that the input loss and the backward-direction loss are required to be not more than 1 dB and not less than 40 dB, respectively, as the polarization-independent optical isolator.

The expanded portion of the core of the core-expanded optical fiber is preferably sufficiently long. That is, the length of the area where the refractive index of the core-expanded portion is distributed in a taper shape is preferably not less than 2000 times as large as the wavelength. In this case, increase in the excess loss can be prevented.

[034]

The polarization-independent optical isolator of Fig. 2 uses an optical isolator element 4B in which fiber-axis

deviation correcting parallel-faced flat plate type polarization beam splitter 5 is not inserted. The light emitted from an end face 8A of a light-emitting side optical fiber 1A and having a small numerical aperture enters a first wedge type polarization beam splitter 6A, and are divided into two polarized components. The polarization plane of each polarized component is turned by a Farady rotator 7.

[035]

While ordinary rays and extraordinary rays are not exchanged, each polarized component enters the second wedge type polarized beam splitter 6B in which the polarized component is converted to parallel beams, and the parallel beams are emitted from the splitter. The parallel beams enters the end face 8B of the light-emitting side optical fiber 1B as they are. As mentioned above, what contributes to the polarized component-dividing function of the wedge type polarization beam splitter 6A is a wedge angle θ, which does not depend upon the thickness of the splitter. Therefore, the length of the isolator element can be shortened.

[036]

At the light-emitting side, the orientation of each polarized component coincides with that of the optical axis of the light-emitting side optical fiber 1B. The core-expanded optical fiber 1B has large tolerance with respect to the positional deviation. In addition, as mentioned above, the width of the wedge type polarization beam splitter 6A can be reduced. Therefore, since the distance between the polarized components 12A and 12B is small, the input loss due to the positional deviation between the polarized components can be made extremely small by using the core-expanded optical fiber 1B.

[037]

Next, the light propagating in the backward direction will be explained. The light 13 emitted from the light-emitting side optical fiber 1B and having a small numerical aperture is refracted, by the second wedge type polarization beam splitter 6B, depending upon its refractive index. The polarization planes of two polarized components are turned in the same direction as in the case of the incident polarized components by the Farady rotator 7. Therefore, while the ordinary rays and the extraordinary rays are exchanged, each polarized component enters the first wedge type polarization beam splitter 6A. In the splitter 6A, each of polarized components 14A, 14B undergoes the refraction depending upon its refractive index, so that the polarized components are not coupled into a single beam. Therefore, the backward-direction light does not enter the light-incident side optical fiber 1A.

[038]

The polarization-independent optical isolator in Fig. 3 employed an element 4C with only one wedge type polarization beam splitter. The light emitted from a light-incident side optical fiber 1A and having a small numerical aperture enters a first wedge type polarization beam splitter 15 in which the light is divided into two polarized components 18A and 18B. When an inclined plane of the first wedge type polarization beam splitter is located at a side of the light-incident side optical fiber 1A as in this embodiment, an incident angle α is preferably not more than $(\theta + 5)°$. The polarization plane of each of the polarized components 18A and 18B is turned by a Farady rotator 16. While ordinary rays and extraordinary rays are not exchanged, each polarized component enters a second parallel-faced flat plate polarization beam splitter 17 where the polarized component becomes parallel beams. The parallel beams are emitted, and enters a light-emitting side optical fiber 1B as they are. As mentioned above, what contributes to a polarized component-dividing function of the wedge type polarization beam splitter 15 is a wedge angle θ, which does not depend upon the thickness of the splitter 15. Therefore, the length of the isolator element can be reduced.

[039]

At the light-emitting side, the orientation of each of the polarized components 18A, 18B almost coincides with that of the optical axis of the light-emitting side optical fiber 1B. The core-expanded optical fiber 1B has large tolerance with respect to the positional deviation. In addition, since the distance between the polarized components 18A and 18B is small, the input loss due to the positional deviation between the polarized components can be made extremely small.

[040]

The light 19 emitted from the light-emitting side optical fiber 1B and having a small numerical aperture passes the second parallel-faced flat plate type polarization beam splitter 17. The polarization planes of two polarized components are turned in the same direction as in the case of the incident polarized components by the Farady rotator 7. Therefore, while the ordinary rays and the extraordinary rays are exchanged, each polarized component enters the first wedge type polarization beam splitter 15. In the splitter 15, each of polarized components 20A, 20B further undergoes the refraction depending upon its refractive index, so that the polarized components are not coupled into a single beam. Therefore, the backward-direction light does not enter the light-incident side optical fiber 1A.

[041]

The polarization-independent optical isolator in Fig. 4 employed an element 4D in which a pair of wedge type polarization beam splitters are used and arranged at respective positions axially symmetrical with respect to a Farady rotator. More specifically, the light emitted from a light-incident side optical fiber 1A and having a small numerical aperture enters a first wedge type polarization beam splitter 15 in which the light is divided into two polarized components 21A and 21B. When an inclined plane of the first wedge type polarization beam splitter is located at a side of the light-incident side optical fiber 1A as in this embodiment, an incident angle α is preferably not more than $(\theta + 5)°$. The polarization plane of each of the polarized components is turned by a Farady rotator 16. While ordinary rays and extraordinary rays are not exchanged, each polarized component enters a second parallel-faced flat plate polarization beam splitter 24 where the polarized component becomes parallel beams. The parallel beams are emitted, and enters a light-emitting side optical fiber 1B as they are.

[042]

At the light-emitting side, the orientation of each of the polarized components 21A, 21B coincides with that of the optical axis of the light-emitting side optical fiber 1B. The core-expanded optical fiber 1B has large tolerance with respect to the positional deviation. In addition, since the distance between the polarized components 21A and 21B is small, the input loss due to the positional deviation between the polarized components can be made extremely small.

[043]

The light emitted from the light-emitting side optical fiber 1B and having a small numerical aperture passes the second wedge type polarization beam splitter 24 where the light is divided into two polarized components 22A and 22B. The polarization plane of each of the two polarized components is turned in the same direction as in the case of the incident polarized components by the Farady rotator 16. Therefore, while the ordinary rays and the extraordinary rays are exchanged, each polarized component enters the first wedge type polarization beam splitter 15. In this embodiment, each of the polarized components 22A and 22B is emitted as 23A or 23B without entering the light-incident side optical fiber 1A.

[044]

In the present invention, if a dielectric multi-layer film is used as the wedge type polarization beam splitter, the optical isolator can be advantageously made more compact. Further, optical parts including the light-incident side optical fiber, the light-emitting side optical fiber, the polarization beam splitter, the Farady rotator, etc. can be bonded together with an optical adhesive or the like. In addition, a so-called integrated type isolator can be produced. In this case, core-expanded optical fibers having undergone a beam-expanding treatment are fixed to a substrate, notches are formed on the substrate, and assembled isolator elements are inserted into the notches. When such an integrated type isolator, the number of the assembling steps can be further reduced.

[045]

(Examples)

[Example 1]

An optical isolator as shown in Figs. 1(a) and 1(b) was produced. Rutile was used as a material for each of the wedge type and parallel-faced flat plane type polarization beam splitters, and the wedge angle θ was set at 19°. The thickness of the parallel-faced flat plane type polarization beam splitter was 170 µm. A magnetic garnet crystal was used as a material for a 45° Farady rotator 4, and its thickness was 375 µm. The total length of the optical isolator element 4A was 1100 µm. The MFD of each of the light-incident and light-emitting optical fibers was 40 µm, and the incident angle α and the wavelength of the incident light were 2.5° and 1.55 µm, respectively, so as to enhance reflection attenuation. The entire element was coated with a non-reflective agent for an adhesive, and fixed with a ultraviolet light-curable type adhesive. At that time, the optical axis of the light-incident side optical fiber was aligned with that of the light-emitting side optical fiber.

[046]

By using the polarization-independent optical isolator thus constructed, a low input loss of 0.35 dB, a high backward-direction loss of 52 dB and a sufficient reflection attenuation level of 60 dB could be obtained without using a lens.

[047]

[Example 2]

An optical isolator as shown in Fig. 2 was produced. Rutile was used as a material for the wedge type plane type polarization beam splitters, and the wedge angle θ was set at 20°. A magnetic garnet crystal was used as a material for a 45° Farady rotator, and its thickness was 375 µm. The total length of the isolator element was 600 µm. The MFD of the core-expanded optical fibers was 40 µm, and the incident angle α and the wavelength of the incident light were 0° and 1.55 µm, respectively, so as to enhance reflection attenuation. The entire element was coated with a non-reflective agent for an adhesive,

and fixed with a ultraviolet light-curable type adhesive. At that time, the distance between the two polarized components of the forward-direction light was about 16 µm.

[048]

In order to minimize the polarization-dependent loss, the light-emitting side optical fiber was arranged almost in a middle position between the two polarization optical axes. At that time, the axis of the light-incident optical fiber was positionally deviated from that of the light-emitting optical fiber by about 11 µm. This isolator had the smaller number of the parts as compared with that in Example 1. By using the polarization-independent optical isolator thus constructed, a low input loss of 0.5 dB and a high backward-direction loss of 57 dB were obtained without using a lens.

[049]

[Example 3]

In the thus constructed polarization-independent optical isolator of Example 2, a dielectric multi-layer type birefringent material was used for the polarization beam splitters. This multi-layer material was obtained by alternatively laminating amorphous silicon and silicon oxide each having a thickness of 70 nm in a total laminating number of 2000, thereby exhibiting birefringent property. The length of the isolator element in the construction of Fig. 2 was 500 µm. In this construction, a low input loss of 0.3dB and a high backward-direction loss of 40 dB were obtained.

(Effects of the Invention)

As is clear from the above explanation, according to the present invention, the compact polarization-independent optical isolator having a high backward-direction loss and a low input loss can be obtained. Further, as compared with the conventional polarization-independent optical isolators, since no lens is used, the number of the parts can be reduced, and the cost can be lessened by eliminating the complicated aligning step.

Claims

1. A polarization-indepedent optical isolator comprises a light-incident side optical fiber having a diameter of a core expanded to give a mode field diameter at an end face being 20 to 50 µm, a light-emitting side optical fiber having a diameter of a core expanded to give a mode field diameter at an end face being 20 to 50 µm, and an optical isolator element provided between the light-incident side optical fiber and the light-emitting side optical fiber, said optical isolator element comprising a first polarization beam splitter located at a side of the light-incident side optical fiber, a second polarization beam splitter located at a side of the light-emitting side optical fiber, and a Farady rotator provided between the first polarization beam splitter and the second polarization beam splitter, and at least said first polarization beam splitter being a wedge type polarization beam splitter.

2. The polarization-independent optical isolator set froth in Claim 1, wherein in order to correct a deviation in an optical axis between ordinary rays and extraordinary rays caused by the first polarization beam splitter, the second polarization beam splitter and the Farady rotator during a forward propagation, an optical axis deviation-correcting element made of a parallel-faced flat plate type polarization beam splitter is provided.

3. The polarization-independent optical isolator set froth in Claim 1 or 2, wherein the second polarization beam splitter is a wedge type polarization beam splitter, and the first polarization beam splitter and the second polarization beam splitter are opposed to each other and turned by a half turn around axes of the optical fibers as a center.

4. The polarization-independent optical isolator set froth in Claim 1 or 2, wherein the second polarization beam splitter is a wedge type polarization beam splitter, and the first polarization beam splitter and the second polarization beam splitter are arranged at locations axially symmetrically with respect to the Farady rotator.

5. The polarization-independent optical isolator set froth in any one of Claims 1 to 4, wherein an incident angle at an end face of each of the light-incident side optical fiber and the light-emitting side optical fiber is not more than 5°.

6. The polarization-independent optical isolator set froth in any one of Claims 1 to 5, wherein the first polarization beam splitter and the second polarization beam splitter are each made of a dielectric multi-layer film.

7. The polarization-independent optical isolator set froth in any one of Claims 1 to 5, wherein the first polarization beam splitter and the second polarization beam splitter are each made of a birefringent crystal.

8. The polarization-independent optical isolator set froth in any one of Claims 1 to 5, wherein the first polarization beam splitter and the second polarization beam splitter are each made of a combination of a dielectric multi-layer film and a birefringent crystal.

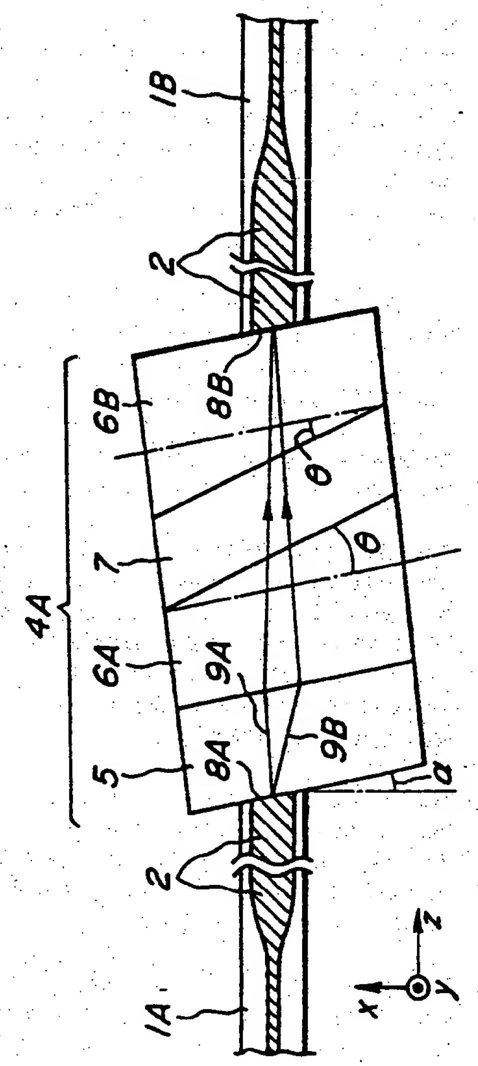

1B
2
8B
6B
θ
θ
7
4A
6A
9A
5
8A
9B
α
2
1A
x
y
z

FIG_1a

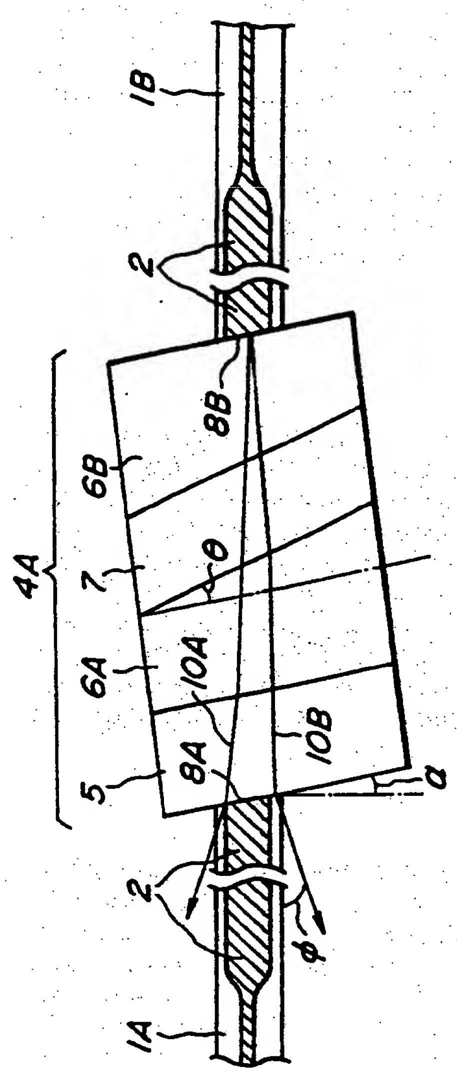

1B
2
8B
6B
4A
7
θ
6A
10A
5
8A
10B
α
2
φ
1A

FIG_1b

FIG.2

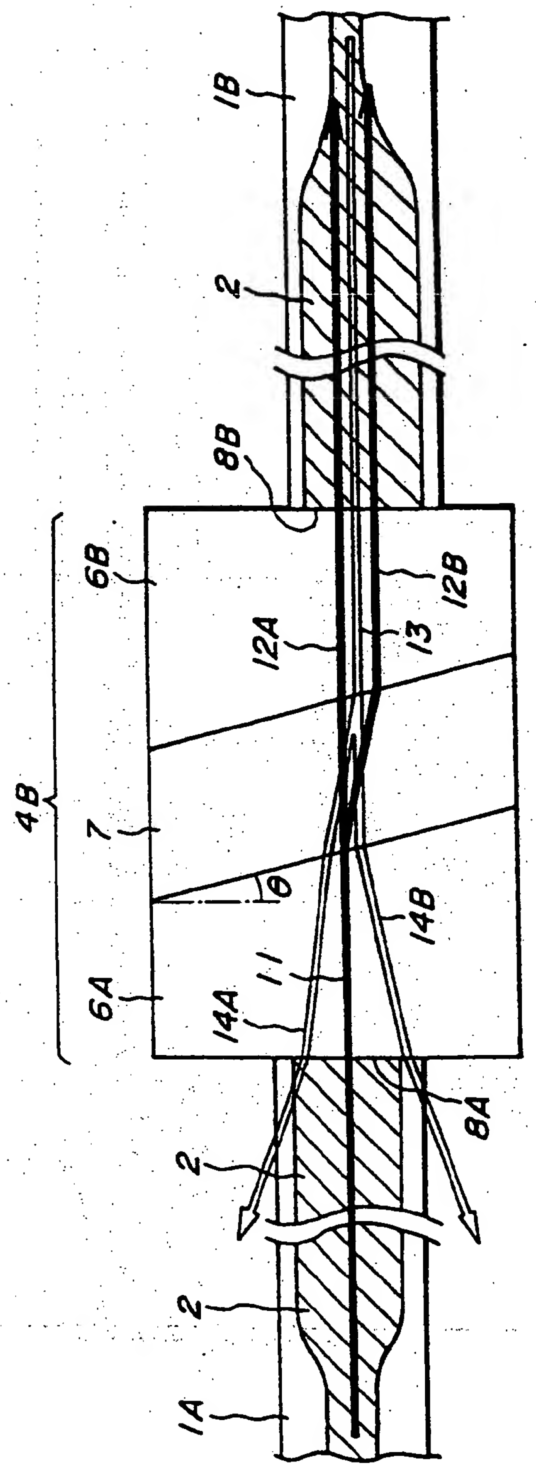
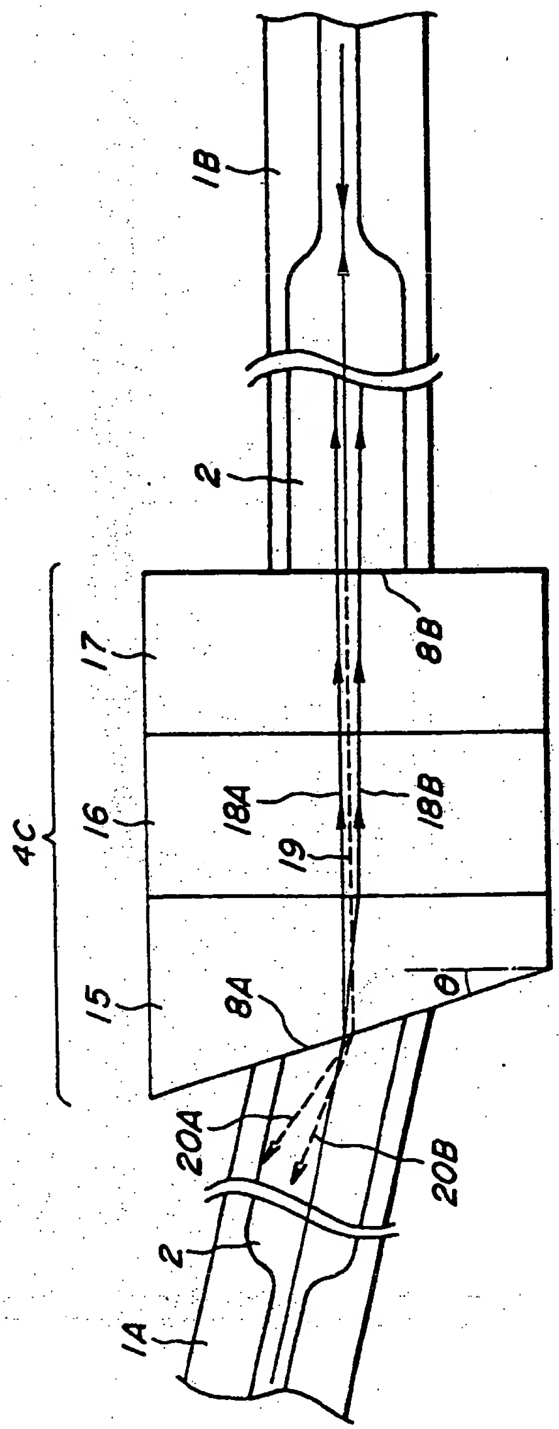


FIG.3



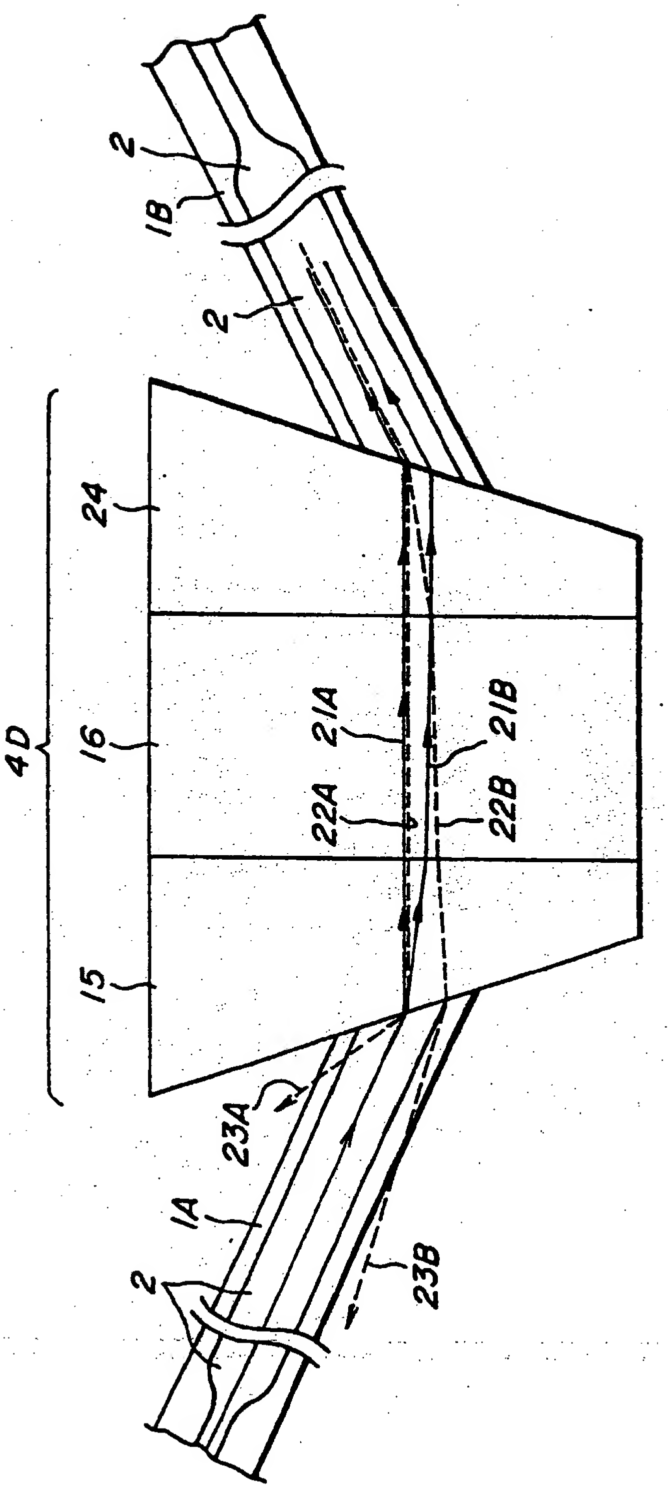
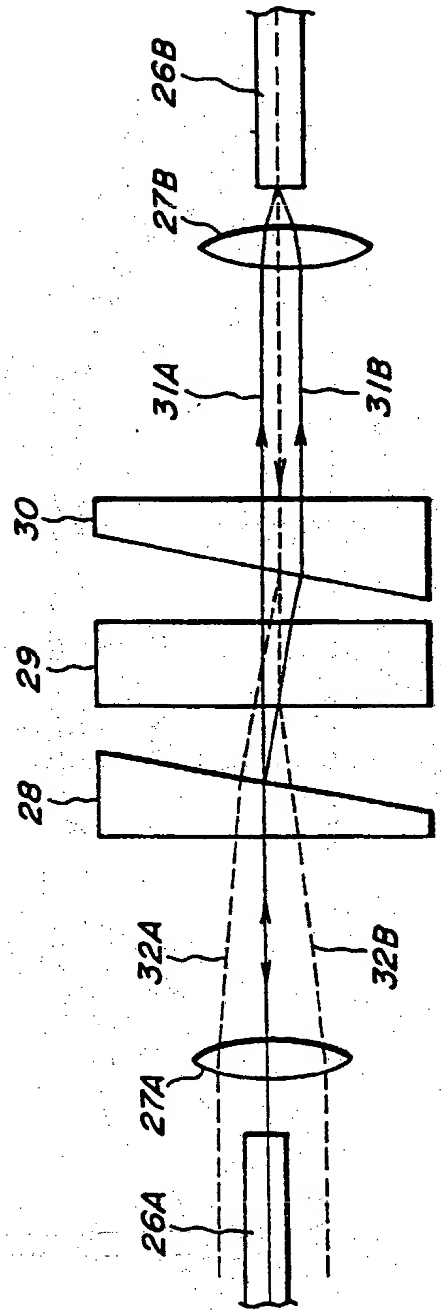


FIG. 4

FIG. 5



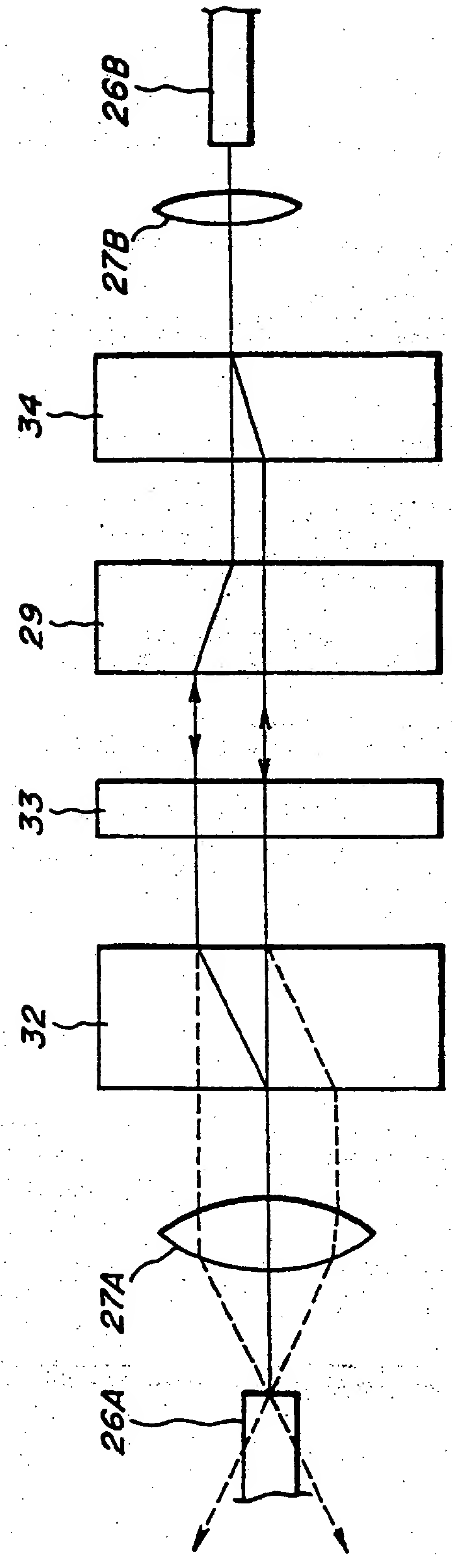


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP96/01910

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl^6 G02B27/28

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl^6 G02B27/28, 5/30, 6/25

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1950 - 1996
Kokai Jitsuyo Shinan Koho 1919 - 1995

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP, 07-43640, A (TDK Corp.), February 14, 1995 (14. 02. 95) (Family: none)	1 - 8
Y	JP, 63-303309, A (Fuji Electric Co., Ltd.), December 9, 1988 (09. 12. 88) (Family: none)	1 - 8
Y	JP, 06-34916, A (Fujitsu Ltd.), February 10, 1994 (10. 02. 94) (Family: none)	2
Y	JP, 61-87101, A (Nippon Telegraph & Telephone Corp.), May 2, 1986 (02. 05. 86) (Family: none)	6 - 8

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
October 3, 1996 (03. 10. 96)	October 15, 1996 (15. 10. 96)

Name and mailing address of the ISA/	Authorized officer
Japanese Patent Office	
Facsimile No.	Telephone No.